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THE VTOL JET FOR A FUTURE V/STOL TRANSPORT SYSTEM

B. Huinink, K. B. Brink

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THE VTOL JET FOR A FUTURE V/STOL TRANSPORT SYSTEM

B. Huinink, K. B. Brink

ABSTRACT. In view of the future demand in civil VTOL aircraft the advantages offered by the development of the DO-31 aircraft provide a basis for further development. An analysis of the aerodynamic characteristics, the aircraft safety, and operating costs leads to the conclusion that the German aerospace industry has high chances in this field. N71-22187#

Summary

Important prerequisites for the realization and successful deployment of /7* a future civilian VTOL transport system, for which a growing market need exists, are:

compatibility with conventional air transportation;

passenger appeal;

acceptable noise levels in the vicinity of VSTOL airports;

a high degree of safety;

economy in deployment.

This paper will show how these prerequisites can be fulfilled with a jet-supported VTOL transport aircraft. This recommendation worked out on the basis of the Do-31 is designed to meet current demands in Germany.

The German airline industry has a good chance, with the development of a jet-propelled VTOL transport aircraft, to turn to national economic advantage the technological lead it has acquired at great cost and not to play just the role of a pioneer. Such a development carries with it minimal risks because of the favorable prerequisites.

1. Introduction /8

In 1969 it became public for the first time that the future development of VTOL passenger aircraft was being seriously considered in the civilian sector.

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* Numbers in the margin indicate pagination in the foreign text.

This shows primarily that the skeleton requirements for a future VTOL transport were elaborated from the civilian sector, i. e., from the airline companies, leading to bid invitations or studies in the USA, in England and also in the FRG (Federal Republic of Germany). Intensive marketing studies in America and Europe preceded these considerations.

Taking into account the cost disadvantages and the operational advantages of a future VTOL passenger aircraft, in which connection the possible lead time vis-a-vis conventional air transportation must be especially emphasized, the future share of the market that VTOL aircraft would command was discovered. With the help of an ICAO prognosis (Figure 1), which includes the incidence of passenger flight up to 1985, a possible division of the market was ascertained through the use of very careful estimates. The fact was naturally taken into account that future VTOL air transport can only be contemplated for short-range and, with reservations, medium-range flights of about 2000 km.

From this cautious estimate and through the evaluation of additional studies on the distribution of air passenger incidence in North America, Europe, and the rest of the world, we arrive at the following possible market sales in number of aircraft (Figure 2): for 1980, 400 aircraft, and for 1985, 700 aircraft. These figures are based on a VTOL passenger aircraft with about 100 passengers and a relatively high productivity which is expressed primarily in the median average air speed of 700 km/h. These market figures are closely verified through the recently published "Anathon Study," wherein it is confirmed that these figures represent the lower limit of sales.

2. Requirements for a Future VSTOL-Transportation System /9

2.1 Important Prerequisites for the Realization of a Civilian VSTOL Air Transport System

The following prerequisites are important for the realization and successful deployment of a civilian VSTOL air transport system:

- compatibility of the system with the conventional air transport system;
- passenger appeal;

the aircraft must have an appeal for the passenger. His comfort must be at least on a par with that found in conventional jets:

- acceptable noise levels in the vicinity of VSTOL airports;

- a high degree of safety;

in view of the anticipated deployment of this aircraft in the direct vicinity of cities and over populated areas, a high degree of safety is required;

- economy in deployment;

the flight fare must be realistic in terms of the travel time saved and in comparison with the total costs and the total travel time involved in other means of transportation.

These viewpoints are the primary and determining factors in the selection of design for the flight equipment. In addition to the flight equipment, the other components of the transport system, shown in Figure 3, must be available at the proper time.

2.2 Principal Requirements for the Future VSTOL Transport Aircraft /10

As for the flight equipment, its requirements are almost similarly defined in England, USA (Eastern Airlines) and in Germany.

The German requirements were jointly worked out by the command staff of the Luftwaffe and by the German Lufthansa Airlines. They call for the same design for the VSTOL military transport as for the VTOL commercial aircraft with as great a number of common construction parts as possible (engines, wings, etc.).

Figure 4 shows a compilation of the most important requirements of the civilian aircraft. Eighty to 100 passengers must be transported over a range of 800 km or 2 x 315 km with a cruising speed of at least 740 km/h and a safe vertical ascent to 600 m above the elevation of the field at 29° C (ISA + 18° C).

The maximal noise level must not exceed a value of 95 PNdB (perceived noise in decibels) at 500 ft., or 150 m, from the point of takeoff.

The direct operating costs per seat-kilometer for a 370-km flight should be no higher than 150% of the corresponding costs in the Boeing 737.

3. Description of and Reasons for the Jet-based VTOL Concept

In the discussion about the basic concept of the future VTOL transport, the propeller concept and the jet concept that we preferred were contrasted. Practical experience data were able to be gathered on both concepts.

The equipment with propeller propulsion was for the most part built and tested in the USA. The designs for this equipment going back 6 to 10 years /11 were founded on military demands which required relatively longer hover periods (up to 30 minutes) and, for that reason, did not allow economically feasible solutions.

The present requirements do not call for hover periods. All that must be assured is the safe execution of vertical takeoffs and landings. Flight tests with the Do-31 show unequivocally that the fuel consumption during this VTOL phase no longer plays a decisive role in the selection of the design concept. The argument repeatedly brought forth relative to the lower hover-flight consumption of the propeller concept is, therefore, one-sided and invalid.

On the basis of our experience and far-reaching research in connection with the Do-31 experimental program, we are convinced that we can best fulfill the present requirements for a VTOL transport aircraft with a jet concept.

In the following section, our Do-231 recommendation, elaborated within the framework of specifications drawn up for a VSTOL transport aircraft for military and civilian use, will be briefly described.

3.1 Brief Description of the Concept Selected

The design of the Do-231 is based, on the one hand, on the proven principles, rules and experience data in the development, construction, and operation of commercial jet aircraft and, on the other, it profits directly from the results of the Do-31 experimental program.

Figure 5 shows a three-sided view of the civilian version of the Dornier-V-Jet Do-231.

It is a high-wing monoplane with swept-back wings, has two cruising engines and four lift engines in the wing pods. Two additional lift engines each are /12 built into the bow and stern of the aircraft.

The selected lift engine arrangement and the resulting number of engines are optimal in terms of safety, maneuverability, and costs. VTOL control takes place by means of the lift engines. For that reason no control cables or additional control valves are necessary.

The two cruising engines of the Rolls Royce RB 220 type are derived from the Airbus engine RB 211 and, therefore, correspond to today's engine technology. They are provided with some modifications (among others, a higher bypass ratio of 6.5) to reduce the maximum noise level.

The Rolls Royce RB 202 lift engines are dual-cycle, dual-shaft without mixture, designed with a bypass ratio of 9.5, especially with a low noise generation, and with a relatively negligible fuel consumption in keeping with the design.

The availability of these engines is not critical for the development of the aircraft. Besides, it is to be noted that in this concept, in addition to the engines, no other power plant components such as airscrews, gears, or shafts need be developed.

The fuselage accommodates 100 passengers, four stewardesses, and 22.3 m^3 of luggage. The design places emphasis on unimpeded access to the passenger and cargo areas. The aircraft has two component flight stairways. Flight preparation can, therefore, proceed quickly and without need of ground equipment.

Figure 6 shows a compilation of important project data.

The designed starting weight amounts to 59,000 kgf. The maximum cruising /13 speed is 900 km/h or 0.81 mach.

The first principal deployment in Figure 7 over a two-part stretch of 315 km with a maximum commercial load, i.e., 100 passengers, and takeoff at a field elevation of 600 m at 29° C (ISA + 18° C) is the determining factor for the design of the aircraft.

In the second principal deployment, the required range of 800 km is exceeded. It amounts to 930 km at a 900 km/h crusiing speed. Both deployments were calculated with "Overhead Destination" and under the most unfavorable conditions in regard to fuel reserves.

The military version, which should be mentioned for the sake of completeness, is distinguished through the shape of the fuselage from the civilian version. Power plants, wings, controls, the engines themselves, and tail unit are essentialy the same.

3.2 Reasons for the selection of the Design

In Section 2.1 a series of important prerequisites for the realization and successful deployment of a civilian VTOL transport system was mentioned. The fulfillment of these prerequisites was the determining factor in the selection of the design and the configuration of the Do-231, as will be shown in the following sections.

3.2.1 Compatibility of the System with the Conventional Air Transport System

The compatibility of the future VTOL transport system with the conventional air transport system, made up of the most important components of flight equipment, air traffic control, and airports, is important, since both systems must work together.

The great flexibility of the aircraft in the selection of approach and de- /14
parture flight paths, as well as approach and departure directions, permits air traffic control to distinguish clearly between CTOL and VTOL traffic in the vicinity of airports. The high flight speed of the VTOL jet aircraft (900 km/h) makes it possible to work it harmoniously into conventional jet aircraft traffic.

For the airports there are no differences (in CTOL and VTOL traffic) in the flight clearance of the Do-231 and conventional short- and medium-range commercial aircraft, such as the DC-9 and the Boeing 737.

The flight equipment in our recommendation displays the minimal possible differences vis-a-vis modern commercial jet aircraft. Accordingly, the differences in the facilities for the maintenance of the aircraft in the airline companies are slight.

3.2.2 Passenger Appeal

The so-called "passenger appeal" constitutes a not-to-be-neglected influence on the deployment of future civilian VTOL aircraft, i.e., an aircraft exercises a certain attraction for the passenger. "Passenger appeal" has a positive influence on the number of seats booked, and hence on income.

For example, the so-called "jet appeal" helped along commercial jet planes to a quick success in spite of an initially high flight fare. The essential features of this "jet appeal" are:

- high flight speed;
- associated with this, a pleasing external appearance;
- high degree of passenger comfort achieved through a quiet and vibration-free flight.

The future VTOL commercial aircraft will offer at least the same high degree /15
of passenger comfort as afforded by conventional jet aircraft. The demand for a quiet, vibration-free flight, associated with comfort, can only be fulfilled with a jet concept.

The Do-231 has -- along with its high flight speed -- all the features that make up "jet appeal." (Figure 8)

3.2.3 Noise

One of the most important, if not most decisive issues for all designs is the question of noise.

The use of the jet concept for civilian VTOL commercial aircraft is made possible through the development of lift and cruise engines with high bypass ratio, generating a minimum of noise. With the current state of technology, the result is that the Do-231 has a noise level of 101 PNdB at 150 m, where 95 PNdB were required. As a result of this more favorable muffling vis-a-vis propeller-driven craft, the noise level drops down to 87 PNdB at 450 m. These values hold true for extreme conditions, i.e., vertical takeoff at 600 m field elevation at 29° C. In all other cases, more favorable values were registered.

Between now and the deployment in 1978, a further reduction of noise level can be assuredly anticipated according to predictions by the engine manufacturers, so that the requirement for 95 PNdB at 150 m will be met. The noise reflection of the lift engines can be reduced by 4 - 6 PNdB through sound-absorbant leading and trailing flaps.

In judging the noise question, it must be mentioned that the duration of the noise effect in the vicinity of takeoff is but very short in the case of VTOL aircraft. Moreover, the noise reflection can be concentrated on a few noise-sensitive areas through the appropriate selection of takeoff and landing paths or of approach and departure directions. The great flexibility of the Do-231 in /16
the selection of flight paths is a distinct advantage.

The favorable influence of steep approach and departure paths on the ground noise level can, for example, be inferred from the fact that a Boeing 707 - 120, equipped with sound-reducing mixing nozzles, radiates sound at takeoff over 20 times as great a surface area and with more than 95 PNdB as the Do-31. The noise level at 150 m is equally great for both aircraft.

In reference to cabin noise, the Do-231 is directly comparable with other jet aircraft.

Other deployment questions such as recirculation and ground erosion did not have to be taken into account for civilian use, since prepared airports are to be used.

3.2.4 Safety

A basic prerequisite for the successful deployment of VTOL aircraft in commercial transportation is a high degree of safety, i.e., the same if not even higher safety requirements must be demanded of a future VSTOL commercial craft as of comparable conventional craft, especially from the point of view of operating over populated areas.

The chief causes of accidents can be grouped into four categories:

- technical failure;
- human failure;
- influence of weather;
- sabotage and unexplained causes.

Although the direct opportunities for influence that the aircraft manufacturers have are restricted to technical safety, the concept and design of an aircraft have an influence not to be overlooked on the cause and course of nearly all accidents. To say it more succinctly, the selection of the concept primarily and decisively co-determines the goal: a high degree of safety. The deployment of VTOL aircraft will take place in the short- and medium-range sector. The result is a relatively short average flight time, which is synonymous with a great number of takeoffs and landings. During the flight phase, i.e., in aerodynamically borne flight, VTOL jet aircraft are directly comparable in safety with conventional jet aircraft. This comes about through approximately the same high speed and the identical handling of the aircraft: cruising engines for producing forward thrust in aerodynamic flight and conventional controls. /17

Major points of stress in safety research for VTOL aircraft are in the takeoff and landing phase. In taking off and landing, VTOL aircraft differ from conventional planes chiefly in their controls and in their propulsion system for attaining a vertical takeoff and landing capability. Control during the hover flight and in the transition is made possible through a fully automatic and manifold redundantly designed attitude regulator. The activation of the necessary control factors, on the other hand, is attained through thrust differentiation, i.e., tilting of the engines. Therefore, safety considerations for the VTOL aircraft in comparison with conventional aircraft can be limited in first approximation to the propulsion system.

In modern conventional passenger aircraft, provisions are made in every flight phase to compensate for the failure of at least one engine or dynamic component contributing to the functioning capability of the propulsion engine. Such a prerequisite must also hold true for VTOL aircraft, since otherwise a VTOL aircraft would not appear to be acceptable in civilian passenger transportation. Fulfilling such a prerequisite is made possible through the jet-based VTOL /18 concept with lift and cruising engines. In the selected layout of 12 lift engines and two cruising engines, it must be emphasized that these constitute in themselves completely independent thrust units, whereby a given failure is admissible. A tilt-wing aircraft, for example, has a lesser number of thrust units; the probability of failure of a thrust unit is then considerably greater than that of an individual lift engine, since it consists of a series arrangement of propellers, blade pitch, gear mechanisms and engines. It must also be said that the failure of a propeller cannot be compensated for. Moreover, there are other considerations that lead inevitably in regard to safety to the selection of the jet concept mentioned here.

In summary, the following are the points which are the basis for the safety superiority of the VTOL jet aircraft with their lift engines over other VTOL concepts: (Figure 9)

under extreme test conditions (max. departure weight, H = 600, ISA + 18° C), the takeoff transition in the event of engine failure can be safely executed through conclusion. The thrustweight ratio does not drop in the process to below 1.5. Even in the case of the failure of both cruising engines, a safe landing can still be effected;

in the overwhelming number of takeoffs and landings, which in practice will take place under more favorable conditions, the safety factor increases considerably, since the available thrust increases and a certain number of double failures may be tolerated;

good control characteristics in VTOL phases by reason of a very slight lag in the lift jets and a high degree of control factors through a favorable arrangement of the engines:

simple assembly of the power plants, no changes in configuration dur- /19
ing the transition from one flight phase to another (eg., no extension or retraction of the lift jets, no folding of the wings);

angle of glide and rate of vertical descent can be selected at will within wide limits. There is no narrowly limited "transition corridor" as in folded-wing aircraft;

crash landings, caused during takeoff and landing transition at low speeds, can be expected to have less serious consequences than crash landings at the high speeds common today. Besides, none of the engines is located in the direct vicinity of the passenger cabin. The fuel tanks are not directly in danger in the case of impact;

the opportunity still exists to terminate the transition in time and to land the aircraft conventionally, i.e., without use of lift jets, on a normal runway.

3.2.5 Direct Operating Costs and Economy

The chief factors effecting direct operating costs are:

- procurement price;
- operating costs;
- maintenance costs;
- speed (flight or average air speed).

From the prescribed procedure designed to ascertain direct operating costs and developed by the DLH (Deutsche Lufthansa) to arrive at supplemental costs for the VTOL and based on the normal DLH operation cost method, a 40 percent higher seat-kilometer cost was calculated for the jet concept described here in comparison with the Boeing 737 over a required stretch of R = 370 km. This figure is clearly under the requirement permitting a 50 percent higher value /20

vis-a-vis the Boeing 737. Over a 930-km stretch the increase in seat-kilometer costs still amounts to only 23 percent. Although the maintenance costs would be more favorable using another method and a special Dornier calculating procedure, the figures given here are based on the costing procedures listed by DLH. Besides, these figures are based on a series of 300 craft.

The recognized higher procurement price for the VTOL jet concept vis-a-vis other VTOL concepts is a consequence primarily of the greater weight at takeoff. The prices published in press reports for the individual VTOL concepts, which differ as much as 50 percent, are not directly comparable, however, since the design of the other concepts is not always based on the same conditions as those on which the Do-231 was based, to wit, VTOL with full load capacity (100 passengers) at ISA + 18° C at 600 m and 102 kgf per passenger, including luggage.

Possible differences in fuel consumption cause, for example, only a 1 percent increase in direct operating costs for a 10 percent higher fuel consumption. In maintenance costs, a considerable advantage vis-a-vis other VTOL propeller concepts can be counted on because of the relatively uncomplicated assembly of the VTOL jet concept.

Another important advantage of the jet concept is the high cruising speed. If we assume that the share of travel time required for transportation to and from the VTOL field is identical for various comparable aircraft, then the aircraft with the higher cruising speed but with the same seat-kilometer costs will always have the advantage.

Under otherwise identical assumptions, for example, a reduction of the cruising speed from 900 km/h to 750 km/h results in an increase of direct operating costs of about 7 percent for a range of 370 km and 10 percent for a range of 800 km. /21

A relatively high cruising speed offers the aircraft owner, moreover, the opportunity of either handling a given incidence of passenger traffic with few aircraft or of accommodating an additional passenger incidence with a given number of aircraft through greater flight frequencies. In the first case, the necessary investments are lower (total procurement price); in the second case, the income of the aircraft owner increases. Both cases work positively to the advantage of the airline companies.

4. Summary and Conclusion

Proposals for approval and comprehensive project studies here and abroad document the fact that there exists a coming need for civilian VTOL transport aircraft. This has been confirmed through extensive marketing studies, especially those carried out in the USA.

The Do-31-E test and its results have created for the Federal Republic of Germany a great technical lead in the area of jet-driven VTOL transport aircraft and provided the requisite conditions for the development of future VTOL commercial aircraft. On the other hand, no practical experience with any other concepts is available in Germany.

With the recommendation elaborated on the basis of the Do-31 for a civilian VTOL transport aircraft, all prerequisites and demands placed on the future VTOL transport system can be met. In this connection, the availability of the intended engines, which will satisfy noise level requirements, is not critical. This concept is unambiguously superior to all others, primarily because of its high degree of safety, which is a basic prerequisite for civilian air transport. The /22 operating costs given here are clearly below the limit set by the Deutsche Lufthansa. Taking into account time-factor advantages and savings in indirect operating costs, we find that the economical deployment of this aircraft appears certain.

Therefore, all prerequisites for a successful development of the aircraft with the lowest possible development risks are met. The German airline industry has, with such a development, a big chance to transform the technological lead acquired at high cost into national economic advantage and to no longer play only a pioneer role.

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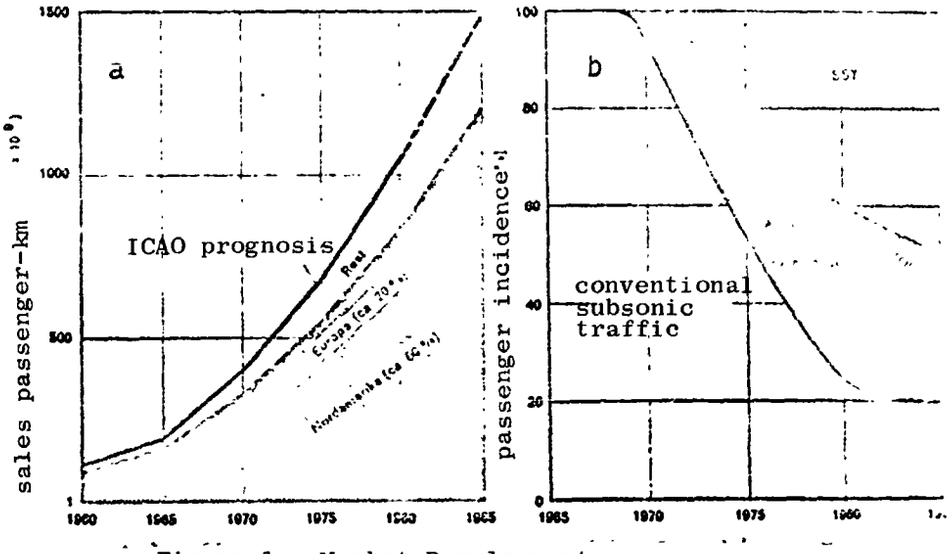

Figure 1. Market Development
a) possible development of passenger incidence
b) possible division of the market

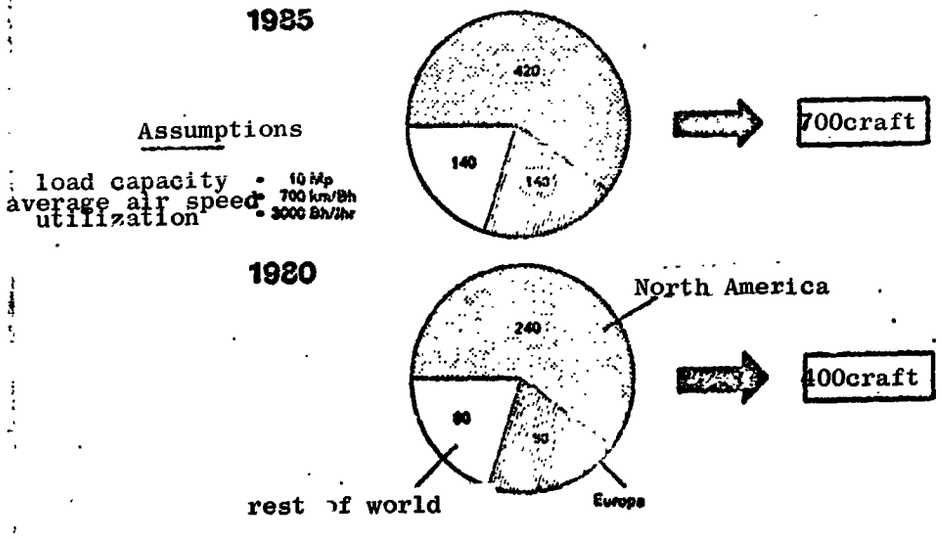

Figure 2. Estimated market potential for VSTOL aircraft.

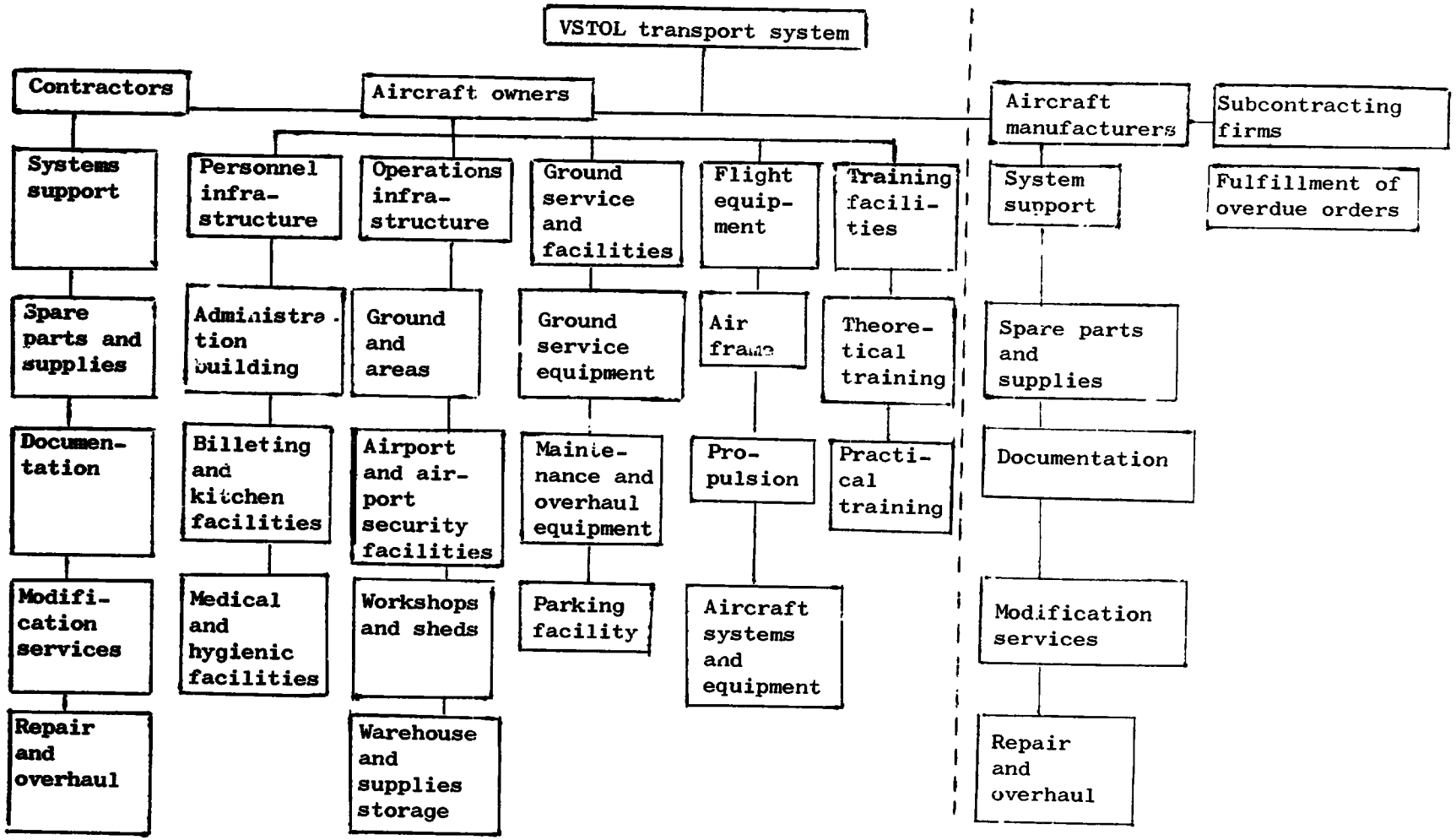

Figure 3. System definition.

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Designed load capacity	80 - 100 passengers
Designed stretch range	800 km or 2 x 315 km
Max. cruising speed	> 740 km/h TAS
Safe vertical takeoff with designed load capacity at	ISA + 18°C, H = 600 m
Top altitude with loss of cruising engine	4,600 m
Max. noise level during takeoff at 500 ft. distance	95 PNdB
Direct operating costs per seat-kilometer for 370 km stretch	< 150% direct operating costs Boeing 737

Figure 4. Principal requirements.

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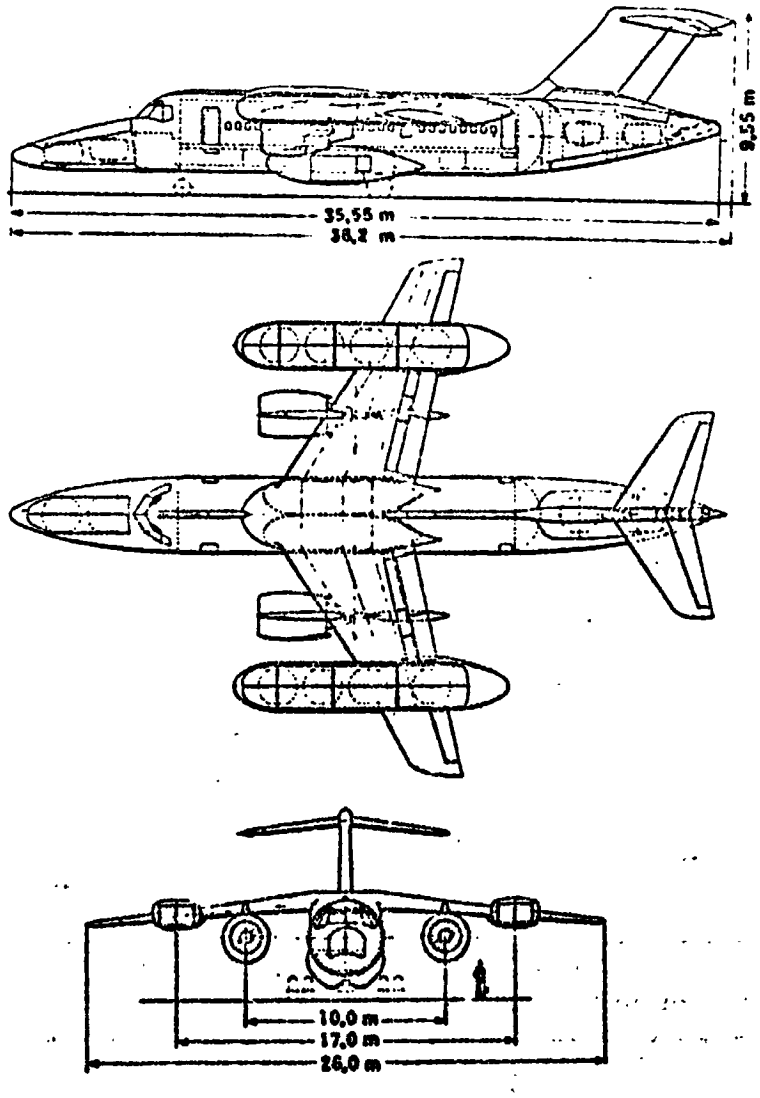

Figure 5. Three-sided view of the DO 231C.

Engine		2x RB 220 Bypass ratio 6.5 12x RB 202-25 Bypass ratio 9.5	/28
Installed thrust ISA, H = O			
Cruising engines	kp	2x 10,850	
Lift engines	kp	12x 5,935	
Total	kp	92,920	
Designed takeoff weight	kp	59,000	
Basic wing surface	m^2	120	
Span-chord	-	5.63	
Wing loading at designed takeoff weight	kp/m^2	492	
High-lift means	-	Double-slotted flaps (externally blown flaps)	
		Do 231 C	Do 231 M
Wing span	m	26.0	26.0
Length	m	35.55	35.55
Height	m	9.55	10.05
Safe maneuvering load factor at designed takeoff weight	-	2.5	3.0
Max. cruising speed	km/h	900	
Max. mach speed	-	0.81	

Figure 6. Essential project data of the Do 231 C.

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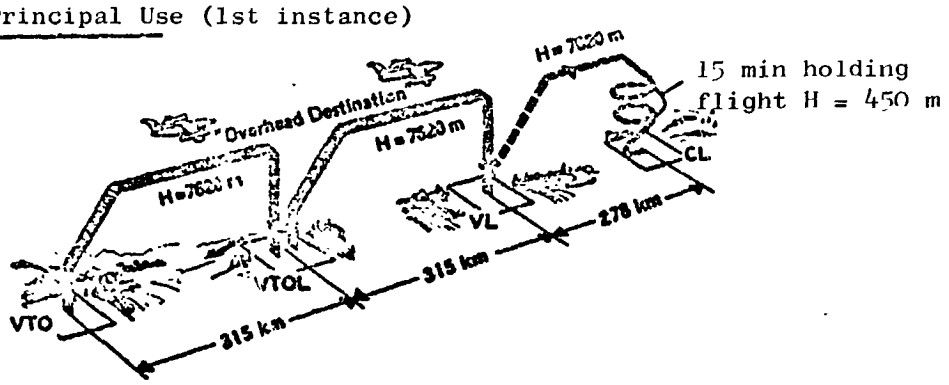
1. Principal Use (1st instance)



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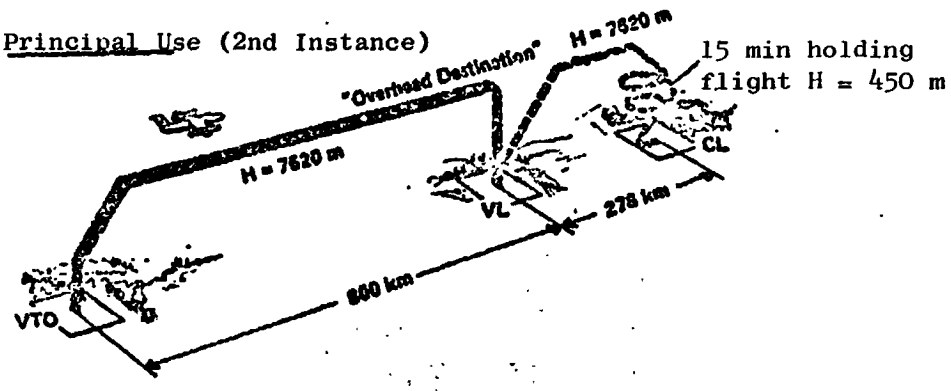

Reserves for both uses:

10% fuel for flight stretch
278 km emergency (detour) flight
15 min. holding flight at H=450 m, including conventional landing.

Figure 7. Deployment profile for principal uses.

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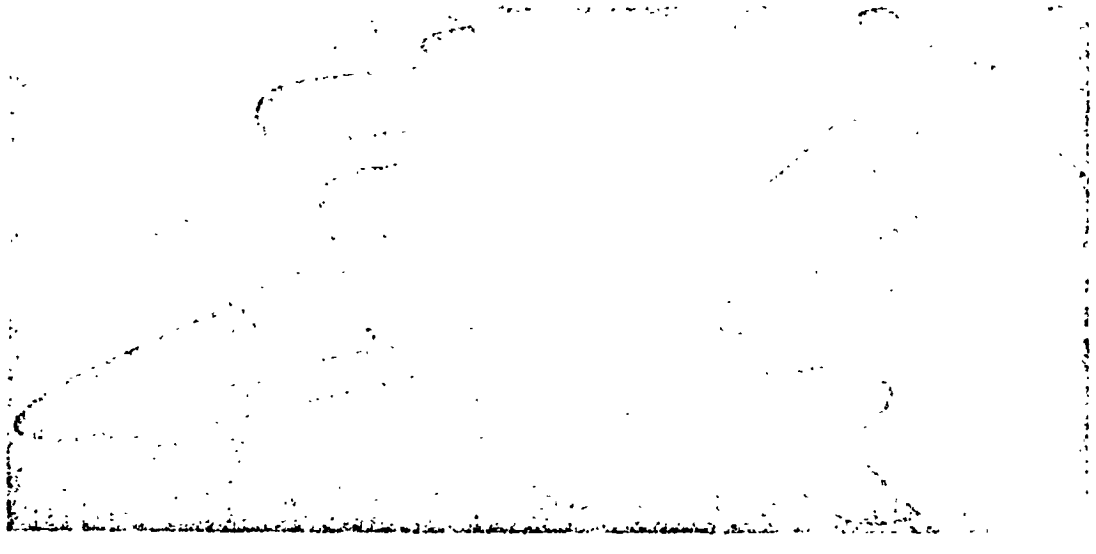

Figure 8. Do 231 C.

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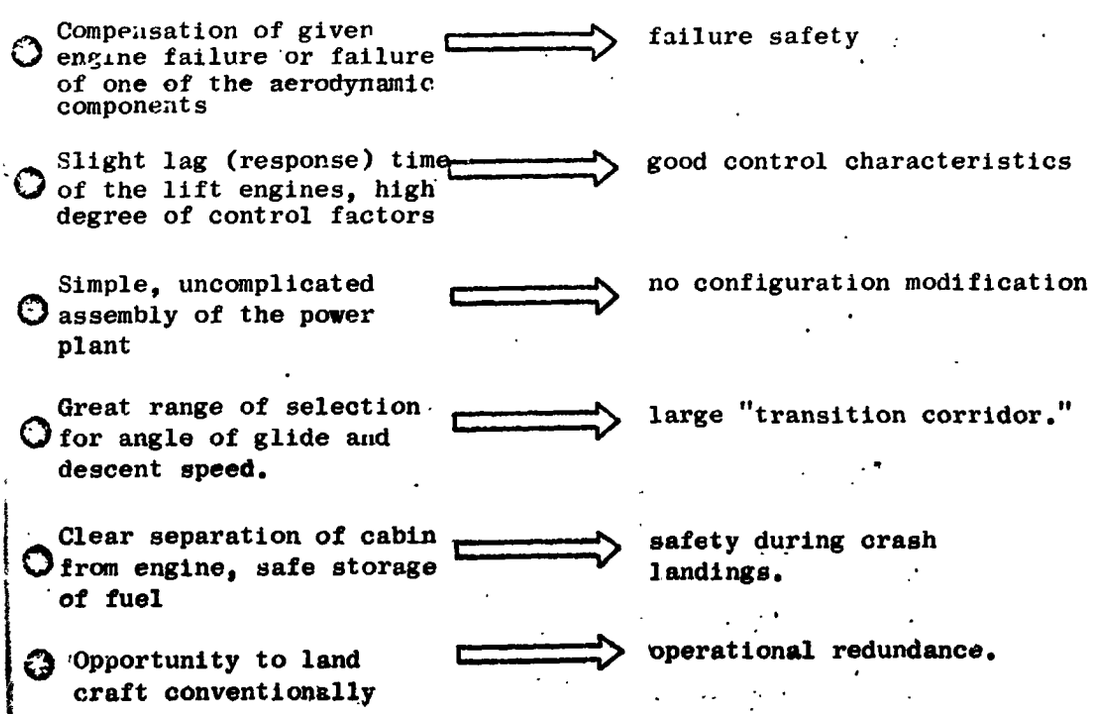
Compensation of given engine failure or failure of one of the aerodynamic components
failure safety
Slight lag (response) time of the lift engines, high degree of control factors
good control characteristics
Simple, uncomplicated assembly of the power plant
no configuration modification
Great range of selection for angle of glide and descent speed.
large "transition corridor."
Clear separation of cabin from engine, safe storage of fuel
safety during crash landings.
Opportunity to land craft conventionally
operational redundance.

Figure 9. Safety points of view for the VSTOL jet concept.

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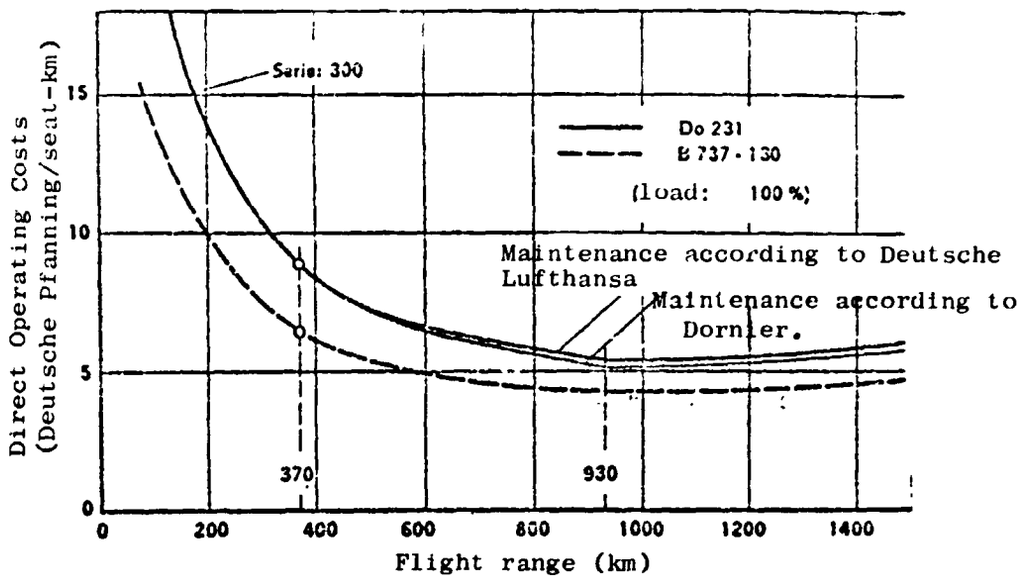

Figure 10a. Direct operating costs.

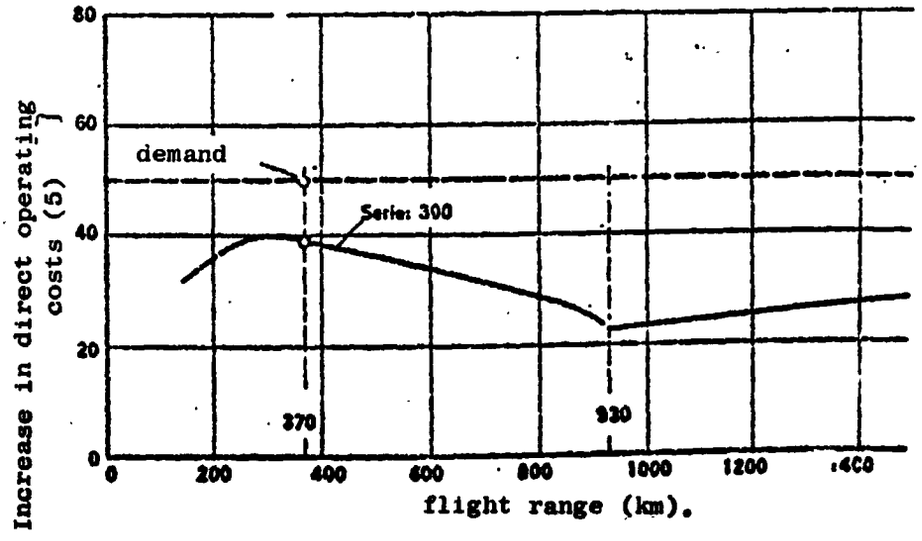

Figure 10b. Increase in direct operating costs vis-a-vis B 737-130.

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